STATUS OF THE UPGRADED VERSION OF THE NRL GAMBLE II PULSE POWER GENERATOR

J. R. Boller, J. K. Burton and J. D. Shipman, Jr.

Naval Research Laboratory

Washington, D. C. 20375

Abstract

The GAMBLE II water dielectric pulse power generator, in 1970, was the forerunner of the high energy (>50 kJ) class of water dielectric generators. It has been redesigned internally to make maximum use of its original outer conductor shell and to optimize it for the positive polarity mode of operation for positive ion beam experimentation. The new design also initiates the use of an oil dielectric multi-channel switch at the output of the pulse forming line. This switch, because of its low capacitance, eliminates the need for an extra prepulse switch. The upgraded version has been tested up to power and energy levels which are nearly twice the original.

The GAMBLE II pulse power generator, designed and built at the U. S. Naval Research Laboratory in 1970 has been modified so that it is now delivering about $1\frac{3}{4}$ times its former power and energy. It is hoped that as the physics experiments now using the generator need more power; the output can be gradually increased until it is up by a factor of about $3\frac{1}{2}$.

The original generator is shown in Figure 1. It consisted of a 215 kJ, 4 nF, Marx generator in a tank of transformer oil that charged a 7 Ω, 7 nF water dielectric, coaxial, intermediate store; which in turn charged a 6 Ω, 6 nF water dielectric coaxial pulse forming line. A single channel, but multi-branching, water output switch self closed near the peak voltage and sent a fast rising power pulse into a 6 Ω, to 1.5 Ω coaxial transformer and delivered 65 kJ into a matched load with 63 ns FWHM. Peak power was about 1 TW.

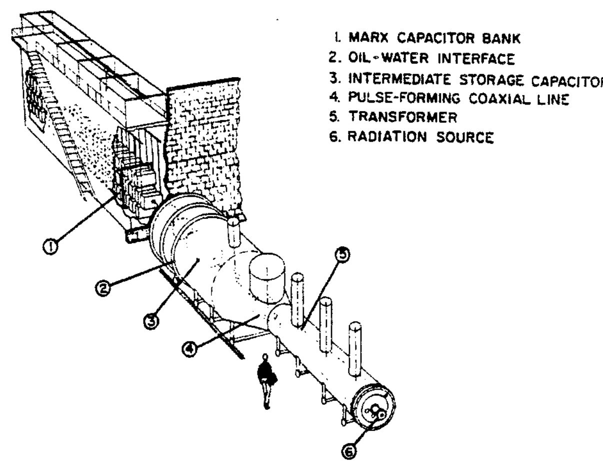

Fig. 1. GAMBLE II Pulse Power Generator in its original form

Figure 2 shows the relatively few modifications which were required to modify GAMBLE II into the upgraded IIA version. The new components of the generator are shown shaded.

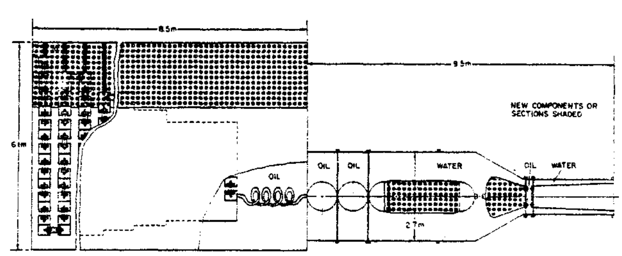

Fig. 2. GAMBLE IIA Pulse Power Generator Schematic

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1979**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Status Of The Upgraded Version Of The Nrl GambLe II Pulse Power Generator**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory Washington, D. C. 20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT
The GAMBLE II water dielectric pulse power generator, in 1970, was the forerunner of the high energy (>50 kJ) class of water dielectric generators. It has been redesigned internally to make maximum use of its original outer conductor shell and to optimize it for the positive polarity mode of operation for positive ion beam experimentation. The new design also initiates the use of an oil dielectric multi-channel switch at the output of the ~ulse forming line. This switch, because of its low capacitance, eliminates the need for an extra prepulse switch. Yne upgraded version has been tested up to power and energy levels which are nearly twice the original.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

We found that by increasing only the height of the oil tank by 6 ft., we could enclose Marx generator components for 520 kJ stored in 13 nF. The expensive stainless steel outer conductor of the water dielectric part of GAMBLE II was left unchanged with the exception that we use only the last half of the original coaxial transformer since the pulse forming line impedance has been reduced from 6 Ω to 3 Ω. The spheres and hemispheres from the original intermediate store inner conductor with the o-ring grooves, etc., required for sealing the connections through the polyurethane diaphragms were used unchanged. The only new part in the intermediate store is the relatively inexpensive cylindrical aluminum section between the end hemispheres.

The impedance of the intermediate store is 6.7 Ω, which is the optimum impedance for storing maximum energy in either the negative or positive polarity mode. Its capacitance is 16 nF including the capacitance of its water output switch.

The pulse forming line impedance is 3.2 Ω, which is the optimum impedance for delivering maximum power to the transformer in the positive polarity mode. It is also a good choice for the negative polarity mode. Its capacitance is 10.4 nF.

The GAMBLE IIA pulse generator has a pulse forming line output switch that is unique in large water dielectric systems. It uses transformer oil instead of water as the medium in which the switch streamers propagate. Since oil has a dielectric constant about 1/36 that of water, the prepulse fed through the output switch capacitance during the charge of the pulse forming line is reduced accordingly. The polyurethane diaphragms that contain the switch oil provide support for the output end of the pulse forming line and the input end of the transformer. After each shot the oil is circulated through a filter for about 15 minutes to clear out the carbonized oil. The oil output switch used until now has been a self closing multi-channel type with 6 or 12 enhanced field, 1 inch diameter electrodes on the positive side. It results in a 10% to 90% current rise time in a matched load of 35 to 45 ns with a prepulse of less than 1%.

The present performance of the generator is summarized in Figures 3 and 4.

	COMPUTED VALUES WITH THE INTERMEDIATE STORE SWITCH RESISTANCE = 0 OHMS	COMPUTED VALUES WITH THE INTERMEDIATE STORE SWITCH RESISTANCE = 2 OHMS	MEASURED VALUES ON SHOT NO. 66
PEAK POWER INTO A 2 OHM NONINDUCTIVE LOAD	2.24 TW	1.79 TW	1.78 TW
FWHM OF THE POWER INTO THE 2 OHM LOAD RESISTOR	64 ns	64 ns	71 ns
10% TO 90% RISE TIME OF THE POWER INTO THE 2 OHM LOAD RESISTOR	48 ns	48 ns	45 ns

Fig. 3. Computed and measured power into a near matched load on the GAMBLE IIA Pulse Power Generator

	COMPUTED VALUES WITH THE INTERMEDIATE STORE SWITCH RESISTANCE = 0 OHMS	COMPUTED VALUES WITH THE INTERMEDIATE STORE SWITCH RESISTANCE = 2 OHMS	MEASURED VALUES ON SHOT NO. 66
ENERGY IN THE MARX GENERATOR	267 KJ	267 KJ	267 KJ
ENERGY INTO THE INTERMEDIATE STORE	199 KJ	199 KJ	199 KJ
ENERGY INTO THE PULSE FORMING LINE	177 KJ	142 KJ	142 KJ
ENERGY INTO THE INPUT OF THE COAXIAL TRANSFORMER	149 KJ	120 KJ	------
ENERGY INTO THE 2 OHM NONINDUCTIVE LOAD	148 KJ	119 KJ	123 KJ

Fig. 4. Computed and measured energy at various stages of the GAMBLE IIA Pulse Power Generator

The right hand column of Figure 3 shows that the measured peak power into a near matched non-inductive load of 2 ohms was 1.78 TW, the FWHM of the power pulse was 71 ns, and the 10% to 90% rise time was 45 ns. The other two columns of Figure 3 show the computed results obtained by analyzing the system with the NRL codes for potential plotting, incremental capacitance calculating, and transient analysis of transmission line systems. The left column shows the values computed with no time dependent or fixed series resistance in either the water or oil switches. The center column shows the values computed when a fixed 2 Ω series resistor was included in the intermediate store output switch. It was found that this resistance has to be added to make the computed and measured values agree as indicated in Figures 3 and 4. The right hand column of Figure 4 shows the measured values of energy at various stages of the water dielectric system. As in Figure 3 the left and center columns are the computed values with zero and 2 Ω for the intermediate store switch resistance. The loss of 68 kJ between the Marx generator and the intermediate store is mainly in the 10 Ω distributed series resistance of the Marx generator circuitry. The loss of 57 kJ between the intermediate store and the pulse forming line is about half dissipated in the series resistance of the water switch and half reflected back into the intermediate store from the water switch. The loss of 19 kJ between the pulse forming line and the load is mainly energy reflected by the inductance of the oil output switch.

Figure 5 shows the measured shape of the current pulse into the 2 Ω load. The peak current was .94 MA with a FWHM of 93 ns. The 10% to 90% rise time was 45 ns. On this shot the output switch closed about 50 ns before peak charge. This results in a greater total shot energy but a somewhat longer rise time than a closure at peak charge. The power and energy delivered to the load are shown plotted below the current. The maximum power was 1.78 TW with a FWHM of 71 ns and the energy

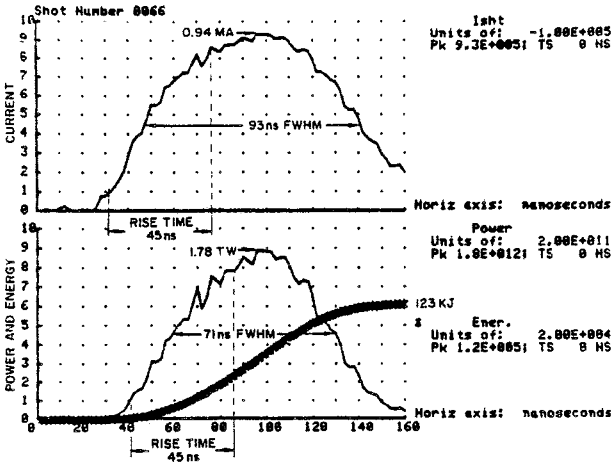

Fig. 5. Measured Current, Power and Energy into a 2 Ω noninductive load

was 123 kJ. The efficiency from the Marx to the load on this shot was 46% which is 53% higher than the 30% efficiency of the original GAMBLE II generator. The efficiency within the upgraded water system between the intermediate store and the matched load is 62%. These efficiencies are very high for such generators.

The complete system can be operated at the Marx generator level of 267 kJ for about 30 to 40 shots before some maintenance is required. At this level of operation the pulse forming line is charged to 4.4 MV in 143 ns and the polyurethane diaphragm on its output end is stressed to 271 kV/cm. If we are able to operate with the Marx generator capacitors charged to 62.5 kV, the total charge will be 520 kJ and the above diaphragm stress would be 378 kV/cm. This stress level on the oil switch diaphragm will probably be the weak link (in regard to breakdown) in the whole system. The output into a matched load at this level would be 3.5 TW and 239 kJ. These last levels will probably not be attainable in the positive polarity mode (which is the only mode of operation to this date). The maximum output in this mode will probably be limited to about 2.6 TW and 180 kJ due to calculated water breakdown in the intermediate store and the pulse forming line.

Our design goal in the upgrade was to get as much power and energy out of the water dielectric system as possible without increasing its outer dimensions and we believe we will achieve this. At least, we are certain that the GAMBLE II generator has shed its conservative label.

The original GAMBLE II generator was funded by the Defense Nuclear Agency. The upgrade was funded by the Office of Naval Research and the capacitors for the Marx generator were furnished by the Sandia Laboratories.